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Can regional transportation and land-use planning achieve deep reductions in GHG emissions from vehicles?

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ABSTRACT

The Intergovernmental Panel on Climate Change estimates that greenhouse gas emissions (GHG) must be cut 40–70% by 2050 to prevent a greater than 2 °Celsius increase in the global mean temperature; a threshold that may avoid the most severe climate change impacts. Transportation accounts for about one third of GHG emissions in the United States; reducing these emissions should therefore be an important part of any strategy aimed at meeting the IPCC targets. Prior studies find that improvements in vehicle energy efficiency or decarbonization of the transportation fuel supply would be required for the transportation sector to achieve the IPCC targets. Strategies that could be implemented by regional transportation planning organizations are generally found to have only a modest GHG reduction potential. In this study we challenge these findings. We evaluate what it would take to achieve deep GHG emission reductions from transportation without advances in vehicle energy efficiency and fuel decarbonization beyond what is currently expected under existing regulations and market expectations. We find, based on modeling conducted in the Albuquerque, New Mexico metropolitan area that it is possible to achieve deep reductions that may be able to achieve the IPCC targets. Achieving deep reductions requires changes in transportation policy and land-use planning that go far beyond what is currently planned in Albuquerque and likely anywhere else in the United States.

1. Introduction

The fifth assessment report by the Intergovernmental Panel on Climate Change (IPCC) estimates that greenhouse gas (GHG) emissions must be cut 40–70% by 2050 from 2010 levels to prevent a greater than 2 °Celsius increase in the global mean temperature; a threshold that may avoid the most severe climate change impacts (IPCC, 2014). In the United States, the transportation sector accounts for 27% of GHG emissions, and transportation's share is growing relative to other sectors (US EPA, 2017). Therefore, reducing GHG emissions from transportation should be an important public policy goal in the United States for avoiding potentially severe climate change impacts.

Prior research generally finds that improving vehicle energy efficiency and widespread adoption of low carbon fuels are the strategies with the greatest potential for achieving deep GHG reductions in the transportation sector (Greene and Plotkin, 2011; Kay et al., 2014; Leighty et al., 2012; Lutsey and Sperling, 2009; McCollum and Yang, 2009; Melaina and Webster, 2011; Olabisi et al.,

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2009; Williams et al., 2012; Yang et al., 2009; Yuksel et al., 2016) and perhaps the only feasible route to achieving cuts that are congruent with IPCC targets. Most studies also acknowledge that no single strategy, alone, can achieve the deep GHG reductions required to meet the IPCC targets. Strategies that encourage more compact and mixed-use development, increase the cost of driving, and shift vehicle trips to lower emitting modes of transportation are also important for achieving deep reductions (Greene and Plotkin, 2011; Kay et al., 2014; Mashayekh et al., 2012; McCollum and Yang, 2009; Melaina and Webster, 2011; Yang et al., 2009); however, without substantial increases in vehicle energy efficiency and fuel de-carbonization, prior studies suggest that even aggressive combinations of these non-technology based strategies will only provide a relatively small portion of the needed reductions (Cambridge Systematics, 2009a; Ewing et al., 2007; Greene and Plotkin, 2011; TRB, 2009).

In this study we evaluate reductions in GHG emissions from vehicle traffic that a metropolitan area may be able to achieve using an extremely aggressive portfolio of strategies that are generally available to state and local governments. These strategies include increasing the amount of compact and mixed-use development, reducing highway capacity, increasing transit capacity and performance while reducing transit costs, implementing a per-mile tax on driving, and increasing the share of trips made by bicycle. While there are certainly other strategies available to local and state governments, we believe that these span the range of the available options and are among those that are likely to be the most effective.

We exclude strategies that aim to increase the energy efficiency of vehicles or increase the use of lower carbon fuels beyond what is expected to occur under currently adopted federal policy. The potential of these technological solutions has been widely reported elsewhere. Additionally, energy efficiency and fuel de-carbonization strategies require strong public policy support to overcome a variety of market failures caused by externalities, loss aversion, and the inability of firms to capture the full benefits of technological innovation (Greene and Plotkin, 2011). Policies such as fuel economy and GHG emissions standards, low carbon fuel standards, and subsidies to encourage the development and adoption of new technologies would be most effective at the federal level. States and local governments with the exception of California are also preempted by federal law from adopting their own fuel economy and vehicle emission standards. Therefore, if the federal government fails to act these technological solutions could be much more difficult to implement in a timely manner.

In our study land-use is indirectly affected by transportation policies and transportation infrastructure and directly by municipal land-use zoning rules. We evaluate how changes in land-use and development density affect GHG emissions through modifying travel behavior. Changes in land-use and development density also affect GHG emission rates from buildings. Prior research generally finds that more compact development is linked with lower residential GHG emissions and energy use due to smaller homes and the greater thermal efficiency of attached dwelling units (Brown et al., 2009; Ewing and Rong, 2008; Lee and Lee, 2014); however, this relationship may be complex and influenced by varying climate conditions, the source of electric power, and type and age of the building stock (Brown et al., 2009; Jones and Kammen, 2014). Prior research has also considered the potential of compact development to reduce GHG emissions from transportation and buildings more holistically by considering lifecycle emissions. For example, Chester et al. (2013) and Nahlik and Chester (2014) use lifecycle analysis in two case studies of transit oriented developments in Los Angeles, California and Phoenix, Arizona. GHG emission reductions from building construction, building energy production, building energy use, vehicle manufacturing, vehicle fuel production, and vehicle fuel use are evaluated for transit oriented and business-as-usual development strategies. The results show that transit-oriented development can reduce GHG emissions from transportation and buildings. In our study we focus on maximizing vehicle emissions reductions and therefor exclude additional GHG emission reductions that would likely result from scenarios that increase development density.

Our study is similar in its aims and methods to Brisson et al's (2012) study of "what it would take?" to achieve the City of San Francisco, California's GHG emission reduction goal of an 80% reduction below 1990 levels by 2050 using strategies under the municipality's control. In that study, the authors conclude that achieving San Francisco's GHG emission reduction goals is impossible without policies that would have to be adopted at a higher level of government. Like Brisson et al. (2012), our study fills an important gap in the literature by evaluating the potential to achieve deep GHG emission reductions from transportation using policies under the control of local and regional governments, in the setting of an actual urban area. The main difference in our study is that we consider an entire metropolitan region (the Albuquerque, New Mexico metropolitan area), which is a region that is more representative of most urban areas in the United States than San Francisco. The Albuquerque metropolitan area has a relatively low density and sprawling development pattern and as a result over 93% of trips are made using a personal automobile. Transit mode share is only 1%. Our study also evaluates even more aggressive implementation of each strategy since prior studies generally find that deep GHG emission reductions are not possible without advanced technology. Other than Brisson et al. (2012), all prior studies that we are aware of have been conducted at a much more aggregate, usually national, scale or have not taken a "what would it take" approach, instead constructing scenarios based on what seems relatively feasible to implement.

Our study is motivated by two observations that suggest to us that there is a very large gap between the emission reductions expected from current regional long range transportation plans and those required to achieve deep GHG emission reductions congruent with the IPCC targets. In California, state law (SB 375 – The Sustainable Communities and Climate Protection Act of 2008) requires that metropolitan planning organizations (MPOs) meet per-capita GHG emission reduction targets ranging from 5% to 18% below 2005 levels by 2035 (California Air Resources Board, 2017). However, California's population is expected to grow by 22% between 2010 and 2035, with much higher growth rates in the most urbanized areas (e.g., 33% in Los Angeles and 38% in San Francisco Counties) according to projections from the State of California Department of Finance. This level of population growth exceeds, often by large margins, the per-capita GHG emission reductions expected in each metropolitan area. This means that total GHG emissions are expected to increase, rather than decrease. The MPO per-capita reduction targets and projections in California do not account for potential state-wide policies that may increase vehicle efficiency (something only California is allowed to do under federal law), de-carbonize fuel or enact some form of road user pricing.

In Albuquerque, New Mexico expectations are similar. The Albuquerque metropolitan area was the site of a U.S. Department of Transportation supported climate change scenario planning study that the authors also participated in, the Central New Mexico Climate Change Scenario Planning Project (Lee et al., 2015). The project aimed to demonstrate how scenario planning can be used to develop a long range regional transportation and land-use plan that mitigates GHG emissions and risk from climate change impacts. The scenario planning project led to the adoption of a regional long range transportation and land-use plan by the Albuquerque area MPO that is expected to reduce GHG emissions by 8.4% over a business-as-usual, trend, scenario by 2040. However, total GHG emissions are expected to increase by 30% over those in the 2012 baseline year due to population growth outpacing per-capita GHG emission reductions (MRCOG, 2015).

While we do not have data on the expected level of GHG mitigation from a large sample of MPOs to understand if the above examples are widely representative of current planning practice, that MPOs in places where mitigating GHG emissions is an important goal are expected to achieve so little raises concerns. The situation in California is particularly concerning given the strong government and popular support for the pursuit of deep GHG emissions reductions there (e.g., California Assembly Bill 32 - California Global Warming Solutions Act of 2006, which requires the state to reduce GHG emissions to 1990 levels by 2020, California Executive Order S-3-05 signed by Governor Arnold Schwarzenegger in 2005 setting a target for an 80% reduction below 1990 levels by 2050, and California Executive Order B-30-15 signed by Governor Jerry Brown in 2015 setting a target for a 40% reduction below 1990 levels by 2030). Furthermore, in a study of regional long range transportation and land-use plans developed by over 50 MPOs, Bartholomew (2006) finds that most plans result is very modest changes in travel demand from business-as-usual, trend, scenarios. The median reduction in VMT from a trend scenario after 20 years is only two percent. The failure of most plans to significantly reduce VMT from a trend scenario (where VMT is much higher than it is today) means that they are also unlikely to result in significant GHG emission reductions, if any, from the baseline year.

The overall aim of our study is understanding the maximum GHG mitigation potential at the local and regional level in absence of the political and financial constraints and biases that seem to limit the aggressiveness of plans developed by MPOs (Brömmelstroet and Bertolini, 2010; Flyvbjerg et al., 2005; Handy, 1992; Hatzopoulou and Miller, 2009; Wachs, 1989, 1990). Evaluating this question is important because if deep, or at least deeper, reductions are possible than this raises a question about the effectiveness of the current regional long range transportation and land-use planning process. The current process seems to be moving us in the complete opposite direction of where we need to go to avoid the most severe climate change impacts.

2. Methodology

Below we begin by describing the region's current long range regional transportation and land-use plans and planning process. We then describe the additional strategies we developed and how we evaluate them using the region's existing modeling capabilities and off model analysis.

2.1. Current regional plans

The Mid Region Council of Governments (MRCOG), the MPO for the Albuquerque region, developed several land-use and transportation strategies based on input from municipal governments, meetings with regional stakeholders, scenario planning workshops, and public meetings. Several initial scenarios were developed and through a series of additional workshops eventually narrowed down to two final scenarios: a trend and an alternative that included strategies aimed at increasing the diversity of land-use, housing and employment density, and transit mode share (Lee et al., 2015).

Each of the scenarios assumed a 52% increase in population and a 46% increase in employment between 2012, the base year, and 2040, the planning horizon. The trend scenario included the current land-use zoning in each municipality in the region, full build out of the highway projects included in the region's previous transportation improvement program (TIP), and no changes to public transit except for the addition of a planned bus rapid transit line. The alternative scenario which was adopted by MRCOG changed zoning to allow denser residential and more mixed use development near transit stops and activity centers and increased commercial density at existing commercial centers, reduced allowable density in flood and fire risk areas, changed zoning to allow re-development of surface parking lots, and provided development incentives for parcels located in existing activity centers and transit corridors. The adopted scenario also included the full build out of highway projects on the TIP and transit improvements that include several new express routes, new Bus Rapid Transit lines and cut existing bus route headways in half on most routes. Table 1 provides several basic performance measures for each scenario included in the Central New Mexico Climate Change Scenario Planning Project and Fig. 1 provides an overview of the study area. Note that GHG emission values in Table 1 are lower than those in Lee et al., 2015 and

Table 1
MRCOG climate change scenario planning project outcomes.

Scenarios	GHG emission inventory (ton/day)	GHG emission per capita (kg/day)	Total daily VMT (million miles)	Vehicle mode share	Non-motorized mode share	Transit mode share
2012 Base	10,370	11.7	19.7	93.2%	5.7%	1.1%
2040 Trend	11,066	8.3	29.0	93.3%	5.7%	1.0%
2040 Adopted	10,454	7.9	27.9	92.7%	5.9%	1.3%

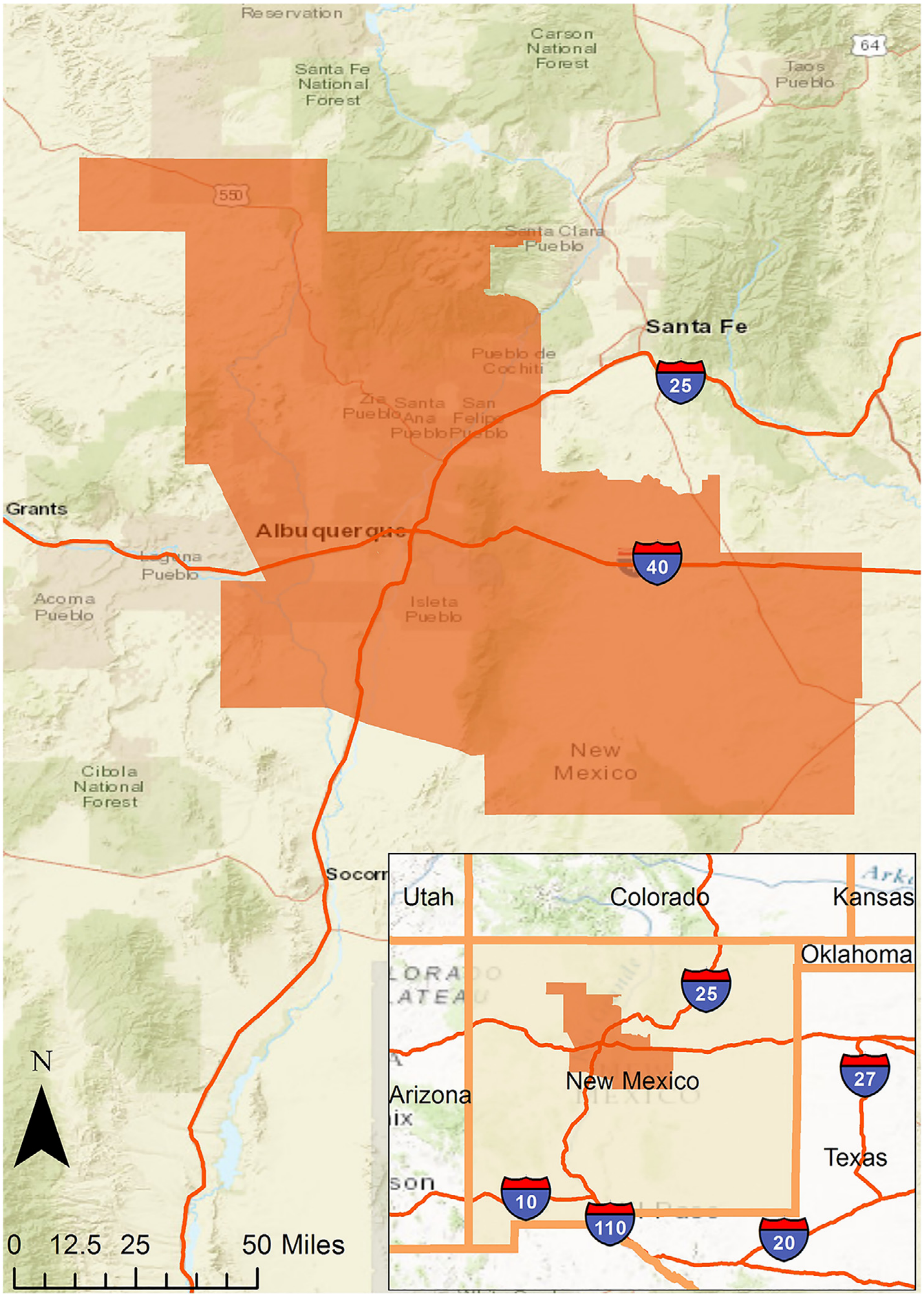

Fig. 1. Albuquerque metropolitan area.

MRCOG's 2040 transportation plan because we have used a more recent version of the U.S. Environmental Protection Agency's (US EPA) vehicle emission model in this study.

The changes to land-use zoning policies in the adopted scenario are believed to represent the largest changes that municipal governments in the region are currently willing to accept. Similarly, the package of highway and transit projects reflects the region's budget and political constraints.

2.2. Integrated land-use, travel demand and emission modeling system

Each of the land-use and transportation planning scenarios developed by MRCOG for the Central New Mexico Climate Change Scenario Planning Project were evaluated with an integrated land-use/travel demand/emission model that was developed by MRCOG

and implemented with the assistance of the authors. We use this same modeling system for the present study. The final report for the MRCOG study, which is available online from the National Transportation Library's Repository & Open Science Access Portal, provides a detailed description of the modeling process (Lee et al., 2015), below we provide a brief summary of its main features.

The first step in this analysis uses UrbanSim, an agent based land-use model, to determine the future population, employment, and land-use mix in each transportation analysis zone (TAZ). UrbanSim predictions are driven by estimates of land and housing values that depend on accessibility, land-use regulations (e.g., zoning), land availability, and the expected population and employment growth in the region. For example, parcels with greater accessibility are more attractive but will also tend to be more expensive; UrbanSim considers these types of dynamics in determining the probability of development for each parcel in the region.

Zonal population and employment output from UrbanSim become input for MRCOG's trip based (4-step) travel demand model that is used to forecast traffic volume and average travel speeds on each roadway link as well as mode share. UrbanSim and the travel demand model work together to model the interaction between land-use and the transportation system. UrbanSim requires base year zone to zone travel times that are produced by the travel demand model to initialize its year by year land-use simulation. The travel demand model uses future year population and employment predictions from UrbanSim to forecast future year travel demand. Future zone to zone travel times from the travel demand model are fed back into UrbanSim during an intermediate time period, 2025, so that future land-use decisions respond to changes in travel time.

The US EPA Motor Vehicle Emission Simulator (MOVES) model version 2014a is then used to create a GHG emission factor look-up table that provides gram per mile emission rates for a range of speeds for each of four roadway types. These emission factors are matched to each roadway link based on roadway type and the speed estimated for that link by the travel demand model. Each link's forecasted traffic volume is then used with the corresponding GHG emission factor to estimate total GHG emissions for each link, which are then aggregated to produce a regional GHG emission inventory for each scenario.

2.3. GHG abatement strategies

In this study, we developed additional GHG abatement strategies that have the potential to produce significant GHG emission reductions. We used the modeling system described above to investigate what changes to either the transportation system, land-use plans or some combination of both would be required achieve deep GHG emission reductions. The main difference in our analysis approach to that of most existing studies is that we do not constrain our analysis to what is generally considered politically or financially feasible. So, for example, we investigate scenarios with much greater density than what exists today, large reductions in roadway capacity, and significant transit system expansion and level of service improvements. The aim of this analysis is to evaluate the size of the gap between current plans and what would likely be required, information that may then allow for greater budgets and political acceptance.

2.3.1. Transit scenarios

The transit strategies include adding one loop bus line to the existing 2040 adopted transit plan along with significant headway and transit fare reductions. We add only one new transit line since there is currently at least one transit line on every major street in the existing plan (Fig. 2). We enhance the performance of existing transit lines by reducing their headways by 50% and 90%. Under the 90% reduction scenario, headways range from 5 to 12 min. While we modeled a 50% reduction scenario, we have excluded this scenario from the results section since the change in GHG emission and transit mode share were negligible. We also eliminate transit fares. Current average transit fares are 65 cents.

2.3.2. Roadway capacity reduction scenario

We develop a scenario that significantly reduces the capacity of roads with more than one lane in each direction. The aim of this scenario is twofold. First, we are interested in if roadways actually require this capacity, and if not, we assume the additional roadway space could go towards improving bicycle facilities, the pedestrian environment or BRT bus lanes. The Albuquerque metropolitan area has many four and six lane urban arterials with relatively low traffic volumes. Additionally, we are interested in how the potential increase in congestion levels would affect travel demand and GHG emissions. Greater congestion could result in shorter trips and greater non-motorized and transit mode share. We removed one lane per direction from all links of the transportation network that have more than one lane in each direction (Fig. 3). This strategy removes lanes from 42 percent of the network in the travel demand model.

2.3.3. Infill and smart growth development strategies

We developed several infill and smart growth strategies that increase development density near transit stops and activity centers and increase commercial density at existing commercial centers. We create each scenario by concentrating population, housing, and employment growth forecasted to occur by 2040 under MRCOG's adopted plan into smaller, currently developed, areas. To do this, we create four increasingly aggressive growth boundaries that define where all future growth will occur (Fig. 4). Growth that was previously forecasted to occur outside of these areas is redistributed to occur within each growth boundary in proportion to the current population density of each TAZ within each boundary. This procedure directs more growth to higher density areas and less growth to lower density areas. The intent is to maintain existing development patterns as much as possible.

The very compact land-use development scenario places all future development into four major existing activity centers which cover just 1.8% of the developed land in the region. These activity centers currently contain the highest concentrations of commercial and retail development in the area, are located along the region's major transportation corridors, and are generally well served by

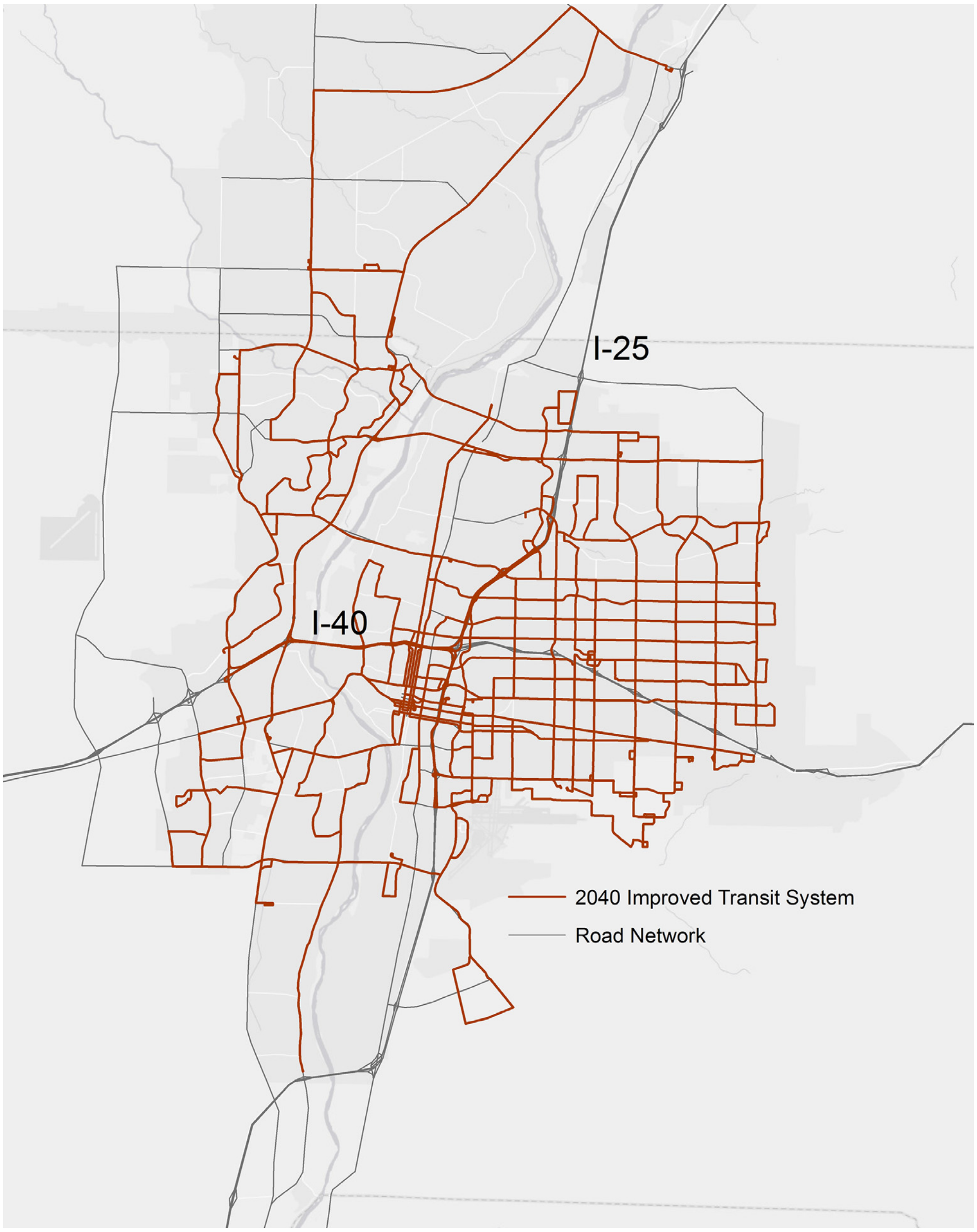

Fig. 2. Transit network.

transit. They include downtown Albuquerque, the area around the University of New Mexico, and two areas of mixed retail and office space located outside the downtown area but still located within the City of Albuquerque. The transit oriented land-use development (TOD) scenario places all future development within one mile of Central Avenue, which is Albuquerque's main transit corridor (contains a Bus Rapid Transit line) and passes through many of the region's largest activity centers including downtown and the University of New Mexico. This scenario directs future development to 12.8% of developed land in the region. The compact land-use development scenario is a less aggressive form of the very compact land-use development scenario, directing future growth to activity centers that make up 5.3% of the region's developed land. These areas are generally well served by transit, have high access the major transportation corridors, and are generally more dense and have a greater diversity of land-use than other parts of the region. The moderately compact land-use development scenario is the least aggressive scenario. It directs all future growth to the current boundary of the City of Albuquerque. This scenario allows development of 47% of currently developed land in the region. We choose Albuquerque (over other cities in the region) because it is the largest city in the region and only out of convenience for modeling a less aggressive land-use scenario. Table 2 compares the population density under each land-use scenario.

The compact development scenarios would be a major change for Albuquerque, but even the most aggressive scenario is not

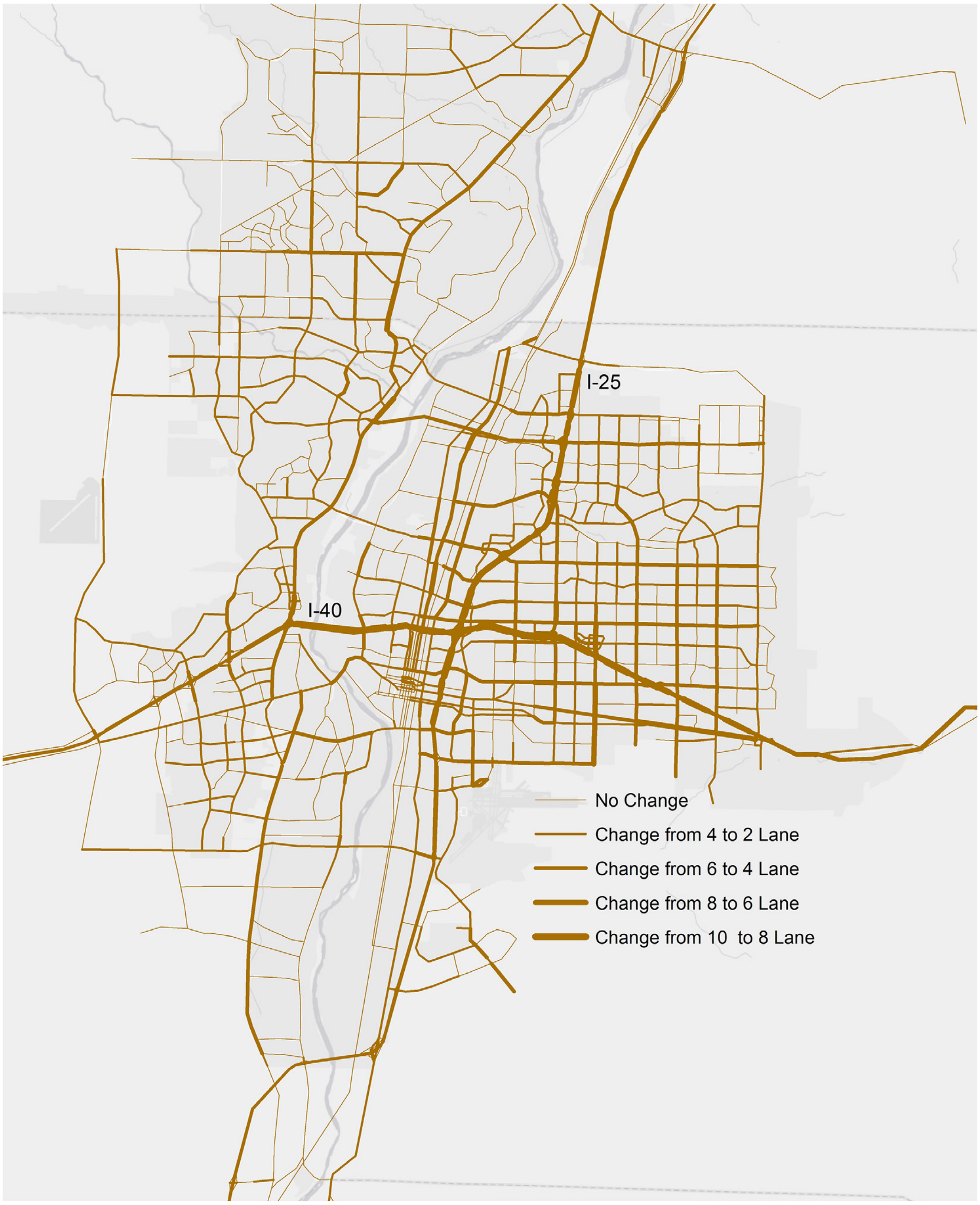

Fig. 3. Roadway capacity reduction.

without precedent within the United States. For example, the areas targeted for growth in the very compact land-use scenario would rank as the 34th highest zip code in terms of population density in the U.S. The downtown areas of New York, Boston, San Francisco, and Los Angles have population densities of 65,753, 28,341, 33,703, and 17,042, respectively. The highest population density zip code in the United States, located in New York City, achieves a population density of 227,800.

2.3.4. Bicycle scenarios

MRCOG's four-step travel demand model, like those used by most MPOs, estimates the number of non-motorized trips (walking and cycling), but not bicycle trips specifically. Additionally, these estimates are mostly influenced by household characteristics (income and vehicle availability), transportation costs, and trip distance. The presence of bicycle and pedestrian infrastructures such as bicycle lanes and wide sidewalks are not a factor even though they are likely to be important. Therefore, we develop two bicycle scenarios that assume a particular level of bicycle mode share: 20% which is similar to the mode share in Davis, CA (the highest

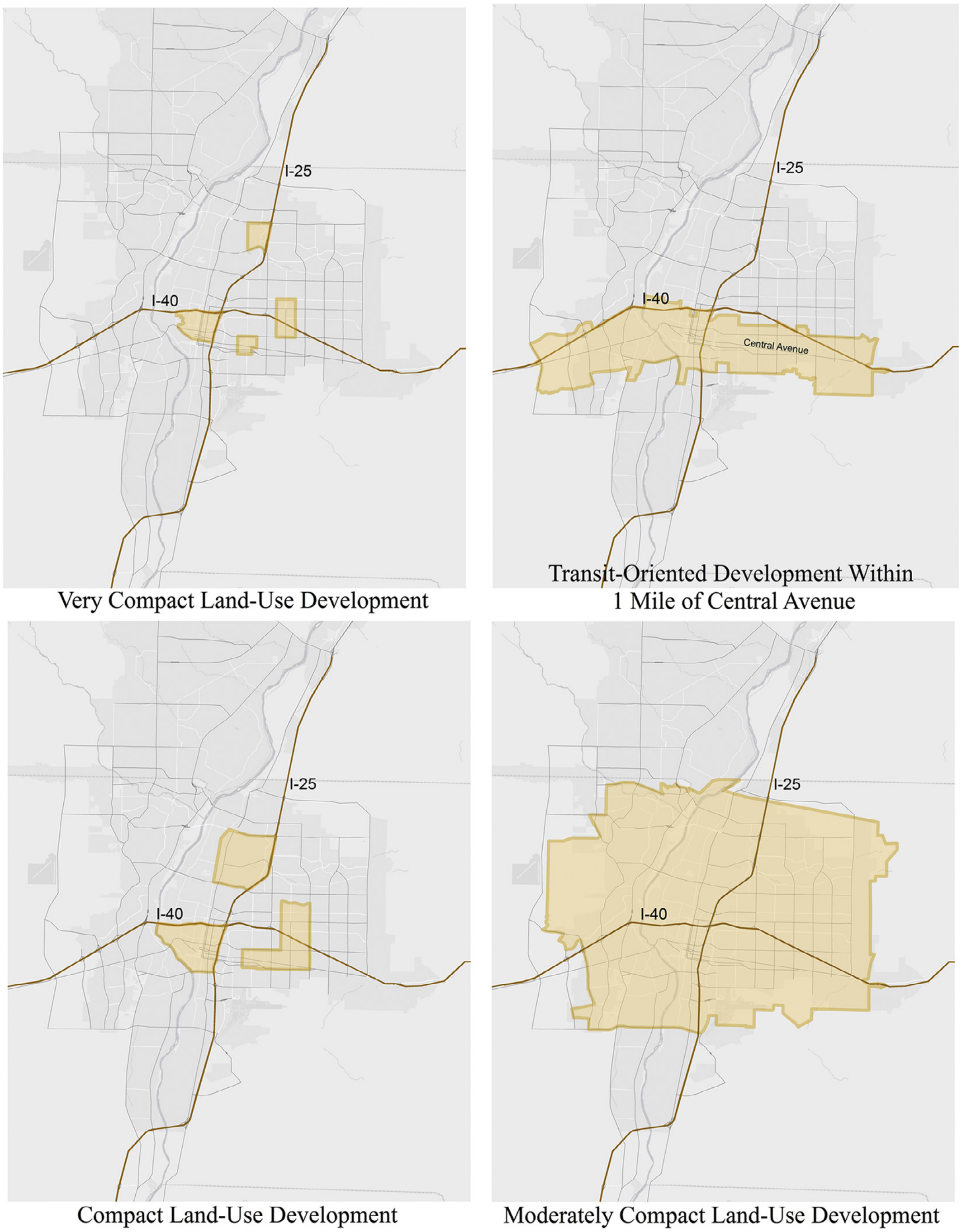

Fig. 4. Boundaries for compact growth scenarios.

bicycle mode share of any U.S. city) and 10% which is similar to mode share in other popular bicycling city's such as Boulder, CO (McLeod et al., 2013). Both of these bicycle mode shares are still well below what has been achieved in several European countries (Haustein and Nielsen, 2016; Heinen et al., 2013). To estimate the effects of increasing bicycle mode share on travel patterns and ultimately the GHG emissions inventory, we first scale down the vehicle O-D trip matrix created by the travel demand model after the mode choice step so that bike mode share can be increased to 10% or 20% while keeping the number and distribution of total trips the same. The adjusted vehicle O-D trip matrix is then used in the assignment step to calculate vehicle traffic volumes and speeds on every transportation link, which are then used with MOVES to estimate a GHG emission inventory.

Table 2
Population density in the target areas under the land-use scenarios.

Development scenario	Population density within growth boundary[a]			
	Very compact	Transit oriented	Compact	Moderately compact
2012	2881	3887	3104	3052
2040 adopted	6303	5435	6030	4319
Compact Development	64,471	12,565	24,021	5397
% Change (Compact Development – 2040 Adopted)	922%	131%	298%	25%

[a] Population density = persons per square mile.

2.3.5. VMT tax scenarios

Existing literature provides a wide range of proposed tax rates that aim to reduce VMT and GHG emissions. Taxes rates have been proposed based on the marginal cost of climate damages caused by GHG emissions (Collantes et al., 2007; Metcalf, 2008), cost of externalities from traffic including congestion, accidents, and pollution (Parry et al., 2007; Parry and Small, 2005), or as a method to reduce the GHG emissions from transportation (Cambridge Systematics, 2009b; Chen et al., 2014; Ross Morrow et al., 2010). These studies have proposed VMT taxes or fuel excise tax equivalents that range between $0.05 per gallon to $6 per gallon. We develop four VMT tax scenarios that add a $0.05, $0.1, $0.15, $0.25 per mile tax to the existing state and federal gasoline excise taxes which are $0.1888 and $0.1840 per gallon, respectively. The tax was modeled by adding the additional per-mile charge to the generalized cost function in the travel demand model. These tax rates are relatively large. Using an average fleet fuel economy of 20.6 miles per gallon (assumption used in the MRCOG travel demand model), the $0.05, $0.1, $0.15, $0.25 per mile taxes are equivalent to a $1.03, $2.06, $3.09, and $5.15 per gallon increase in the gasoline excise tax, respectively.

2.4. Scenarios that combine strategies

We evaluate each scenario alone and in combination with the other strategies since it is unlikely that any single strategy would be completely effective or efficient. While we do not evaluate every possible combination, we create a series of scenarios that bundle increasingly aggressive versions of each individual strategy discussed above. For example, we combine the highest VMT tax with the most compact development scenario. Modeling the combination of strategies allows us to evaluate their combined mitigation potential which is likely different than the sum of their individual mitigation potentials. Table 3 describes each strategy and strategy bundle that we model.

3. Results and discussion

No single strategy is likely to achieve even a 40% reduction in year 2012 GHG emissions by the year 2040, which is the low end of the emission reductions called for by the IPCC (Fig. 5). A high VMT tax would achieve the largest reductions, and taxes higher than what we have modeled would likely achieve more. The potential for compact development is more limited than for VMT taxes. The

Table 3
GHG emission abatement strategies.

Scenario	Scenarios description[a]
Transit	90% reduction in bus headway + eliminating transit fares (transit improvement)
Roadway capacity reduction	One lane reduction from links with 2 or more lanes per direction
VMT tax	$0.05 per mile VMT Tax $0.10 per mile VMT tax $0.15 per mile VMT tax $0. 25 per mile VMT tax
Bicycle	20% bike mode share 10% bike mode share
Smart growth	Very compact land-use development Transit oriented development (TOD) Compact land-use development Moderate compact land-use development
Strategies bundles	Very compact + transit improvement + $0.25 VMT tax Compact + transit improvement + $0.10 VMT tax Moderate compact + $0.05 VMT tax Very compact + transit improvement + $0.25 VMT tax + 20% bike + lane reduction Compact + transit improvement + $0.10 VMT tax + 10% bike mode share

[a] All scenarios are applied to MRCGO's adopted 2040 long range transportation and land-use plan.

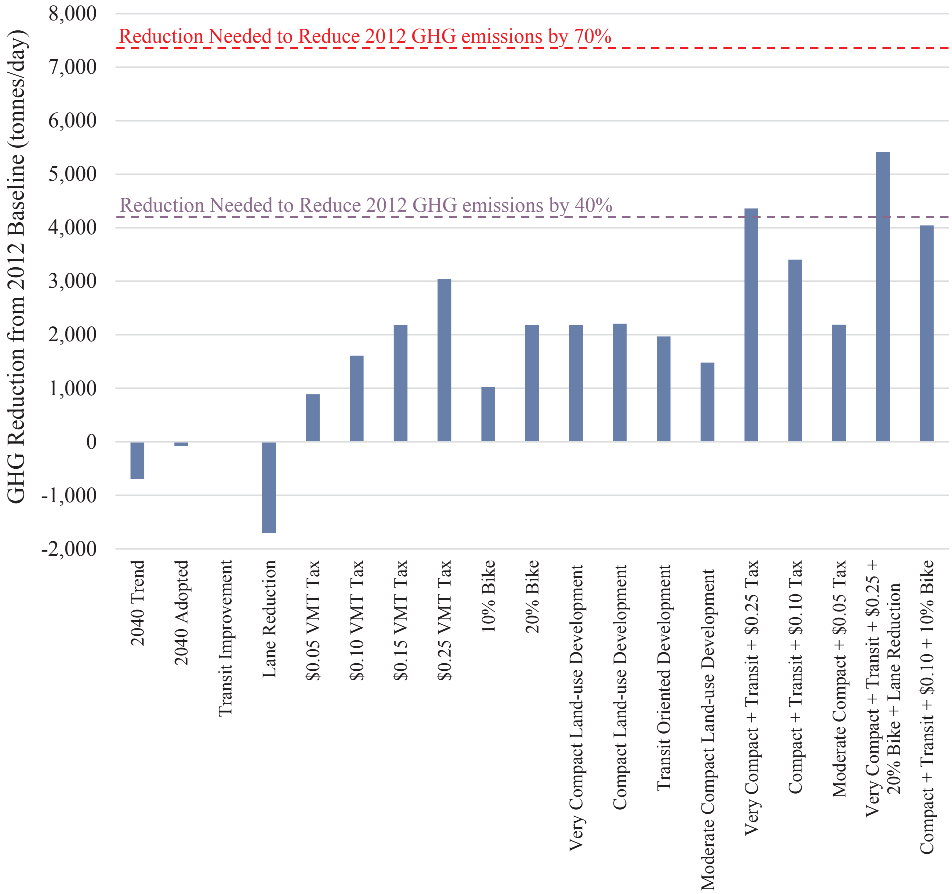

Fig. 5. GHG reductions from MRCOG's 2040 trend scenario.

very compact and compact development scenarios achieve about the same GHG reductions, and just a small amount more than the transit oriented development scenario, even though the very compact development scenario is much more compact. This suggests that the potential for compact development, alone, has its limits. Increasing the share of trips made by bicycle had a relatively large effect on reducing GHG emissions as expected since we forced the model to create the prescribed bicycle mode shares. What is more interesting, however, is that achieving a 20% bicycle mode share would be just as effective in reducing GHG emissions as a relatively high VMT tax ($0.15 per mile) or very compact development. Transit improvements had little effect on GHG emissions. The ineffectiveness of improving transit service may have occurred since the Albuquerque metropolitan area generally has low levels of congestion and a sprawling land-use pattern, two factors that make driving a car relatively attractive. Transit level of service therefore may not be a binding constraint to increasing transit demand in Albuquerque.

Surprisingly, the results indicate that removing roadway capacity would result in a relatively large increase in GHG emissions. This is caused by increasing congestion (see Table 4) which results in higher per mile GHG emission rates. Our original hypothesis was that reducing highway capacity would reduce vehicle travel demand due to increasing congestion levels which would then reduce GHG emissions. While this scenario did reduce average trip distance and VMT per capita, the increasing GHG emissions caused by congestion more than outweighed the GHG emission reductions from these.

As expected, combining strategies results in greater GHG emission reductions. Combining the most aggressive form of each strategy would result in at least a 40% reduction in GHG emissions by 2040, but would not achieve the 70% target. Combining the most moderate form of each strategy would not achieve the 40% reduction target; however, it would achieve GHG emission reductions that are equivalent to the most aggressive compact development scenarios, a 20% bicycle mode share or the relatively high $0.15 VMT tax. In each case, the GHG emission reductions from the combined strategies are also less than the sum of the individual strategies. This is most apparent for the most aggressive strategies. A potential explanation for this result is that a large portion of the Albuquerque metropolitan area is already built and much of the area has a low density development pattern. The result is that some portion of the population is locked into a land-use pattern that requires some minimum amount of vehicle travel. The compact development scenarios improve conditions for the population living near the areas covered by these scenarios but do little for those already living elsewhere. Furthermore, the areas targeted for more compact development are areas that are already more densely populated and have a greater mix of land-uses. The population living in these areas are therefore also more likely to reduce their travel or switch modes when taxes are raised. People living elsewhere have fewer options for avoiding higher taxes.

Table 4
Traffic performance measures and their change from 2012 base scenario.

Scenarios	Ave. trip distance (miles)		Percentage of links with V/C > 1		Daily VMT per capita		Ave. PM speed (MPH)	
	Value	Change	Value	Change	Value	Change	Value	Change
2040 Trend	7.9	0.8%	7.8%	238.9%	21.9	−2.2%	23.7	−35.8%
2040 Adopted	7.6	−3.9%	7.0%	205.2%	21.0	−5.9%	25.7	−30.4%
Transit improvement	7.6	−3.7%	6.8%	194.8%	20.9	−6.6%	26.0	−29.5%
Lane reduction	7.5	−5.1%	26.9%	1072.5%	20.5	−8.5%	12.2	−67.0%
$0.05 VMT tax	7.1	−9.7%	5.4%	136.7%	19.4	−13.4%	28.4	−22.9%
$0.10 VMT tax	6.7	−14.5%	4.6%	99.6%	18.1	−19.2%	30.9	−16.2%
$0.15 VMT tax	6.4	−18.3%	3.7%	59.8%	17.0	−24.1%	32.9	−10.8%
$0.25 VMT tax	6.0	−23.9%	2.7%	17.5%	15.3	−31.6%	35.9	−2.8%
10% Bike	7.6	−3.4%	5.5%	138.4%	19.2	−14.2%	28.9	−21.7%
20% Bike	7.6	−3.2%	4.1%	77.3%	17.1	−23.4%	33.0	−10.6%
Very compact land-use development	6.1	−21.9%	5.2%	128.8%	17.0	−24.0%	32.8	−11.1%
Transit oriented development	6.1	−22.3%	4.2%	81.7%	17.1	−23.6%	34.3	−7.1%
Compact land-use development	6.3	−19.5%	3.7%	62.9%	17.5	−21.8%	32.9	−10.8%
Moderate compact land-use development	6.5	−17.3%	5.0%	117.0%	18.4	−17.8%	30.4	−17.5%
Very Compact + Transit + $0.25 Tax	5.0	−36.5%	1.8%	−23.6%	12.6	−43.7%	39.8	7.9%
Compact + Transit + $0.10 Tax	5.5	−30.3%	2.3%	−0.4%	14.7	−34.3%	38.2	3.6%
Moderate compact + $0.05 Tax	6.1	−22.4%	3.8%	64.2%	17.0	−23.8%	32.7	−11.3%
Very compact + Transit + $0.25 Tax + 20% Bike + Lane reduction	5.0	−36.5%	4.0%	73.4%	10.2	−54.4%	34.5	−6.6%
Compact + Transit + $0.10 Tax + 10% Bike	5.5	−30.2%	1.6%	−29.3%	13.4	−40.1%	39.7	7.5%

While interpreting the results, it is also important to note that our analysis uses 2012 as the base year and 2040 as the planning horizon year. This planning period aligns with MRCOG's planning process and the models they developed. The IPCC targets are defined as reductions from a base year of 2010 by the year 2050. If we extended our analysis by another 12 years the impact on our results is unclear. After 2040 further reductions in per mile vehicle GHG emissions are very minor based on results from US EPA's MOVES model, where most of the reductions occur in the first half of the analysis period. With little additional reductions from the vehicle fleet, no new GHG mitigation policies, and an expectation of continued population growth, GHG emissions could begin to increase from their 2040 levels.

In addition to evaluating the GHG mitigation potential of each scenario, we also evaluated their impact on typical long range, regional, transportation planning performance measures (see Table 4 and Fig. 6). With the exception of the lane reduction strategy, every strategy performs better at reducing congestion (increasing average speed and reducing the number of roadway segments where demand is forecast to exceed capacity), reducing vehicle travel (VMT and average trip length), and at increasing the use of alternative modes of transportation than MRCOG's adopted plan. Strategies the achieve large GHG emission reductions also achieve significant gains in mobility and accessibility, though in each case congestion is still expected to increase over 2012 levels. The performance measures also reveal differences in how each strategy achieves GHG emission reductions. High VMT taxes and compact development both have similar effects on trip distance and VMT; however, higher taxes result in less congestion while compact development results in higher non-motorized and transit mode shares. The transit oriented development strategy was also effective at increasing transit mode share and was slightly more effective than increasing transit level of service. These results suggest that without a supportive land-use pattern, higher taxes or better transit service do little to promote the use of alternative modes of transportation.

The results indicate that to reduce the GHG emissions to levels congruent with the IPCC targest, an average resident of the Albuquerque metropolitan area needs to drive no more than 12.6 miles per day, which is about 42% and 40% less than what is expected under the trend and adopted scenarios, respectively. It is also 30% less than what current residents of New York City drive, or 50% less than Boston's residents (Federal Highway Federal Highway Administration, 2016).

4. Conclusions

Our study highlights the large changes in the way the Albuquerque metropolitan area must grow and travel in order for its surface transportation sector to make a proportional contribution to the IPCC's GHG emission reduction targets of 40–70% by 2050 in the absence of greater than currently forecasted changes in transportation technology. The Albuquerque metropolitan area would need to grow much more compactly than anything that is currently under consideration, would need to impose a very high VMT tax, and go much further to increase bicycling. While what is needed is far from what is currently being planned, it is also not outside the realm of what is possible. The compact development scenarios do not require moving the existing population (e.g., abandoning the suburbs that have been built) but rather directs future growth to areas that are relatively dense and have a greater than average diversity of land-uses. In the most extreme case, the very compact development scenario, densities are very high but still less than some areas of New York City today, while the other compact development scenarios produce densities similar to what exists in the central areas of many U.S. cities. The high VMT tax is similar to the equivalent gasoline tax currently imposed in many European countries.

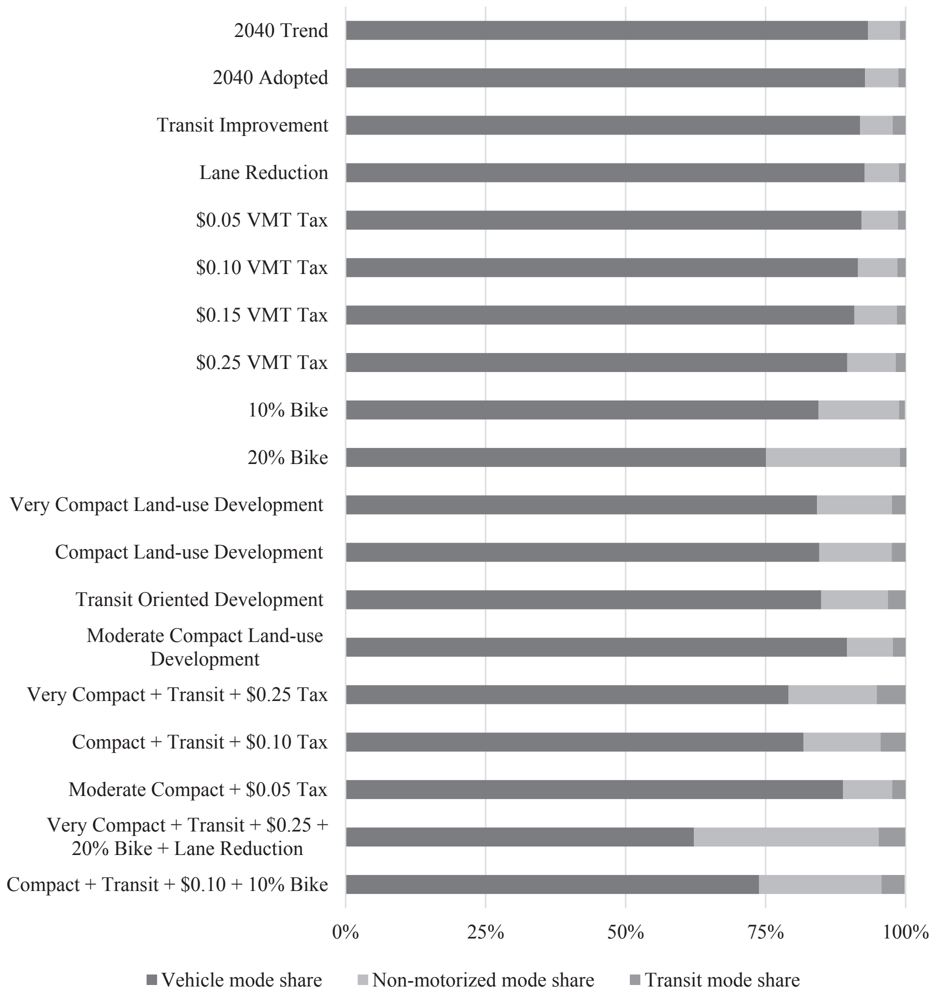

Fig. 6. Comparison of mode shares.

Furthermore, a 10–20% bicycle mode share, while much greater than Albuquerque's current bicycle mode share of 1.8%, is still below what has been achieved in several European cities and close to current bicycle mode shares in Davis, California and Portland, Oregon, respectively. Combinations of these strategies can also produce significant GHG emission reductions with relatively modest versions of each strategy.

While our study focuses on the Albuquerque metropolitan area, we expect that similar results could be produced in other metropolitan areas in the U.S. No metropolitan area that we are aware of has created a long range regional transportation and land-use plan that is expected to produce GHG emission reductions commensurate with the IPCC targets (this is based on the interim results of a study we are currently conducting). To do so, would likely require large and unprecedented changes to what has been planned. Our scenarios are not very creative and probably not the most efficient; however, they demonstrate what can be achieved by starting with a goal and working backward to identify ways to potentially accomplish it. The largest barrier to creating more effective long range plans appears to be a political or citizen mandate to do so. With commonly used planning tools we were able to identify strategies that are likely to produce large GHG emission reductions and also improve mobility and accessibility.

We argue that the typical planning process, which considers constraints such as funding availability, political feasibility, and the current regulatory environment (e.g., local zoning) in developing scenarios that are then modeled and evaluated is problematic and one cause of incremental plans that are ineffective at significantly reducing GHG emissions and achieving other transportation system goals. The common practice of comparing an adopted plan's performance to Strawman business-as-usual or do-nothing trend scenarios is also problematic. These comparisons inevitably find that doing something is better than doing nothing. Understanding how far off we are from meeting important goals, such as achieving deep GHG emission reductions, and the type and scale of changes required to meet goals, may be information that could change the dynamics of the planning process as well as its constraints. While current planning practice may identify the gap between expected GHG reductions and those that would be required to meet targets like the IPCC's, it does not identify the additional policies, plans and infrastructure that would be needed to fill the gap. Citizens, policy makers, and planners therefore may not fully grasp the scale of changes that may be required should technological advances

fail to provide significant GHG emission reductions soon enough.

Finally, several limitations to our study should be noted. In this study we use a 4-step travel demand model which has several limitations. First, there is no representation of the bicycle facility network. We assume bicycle mode shares in our analysis which in practice would be produced from improvements to bicycle facilities along with supportive land-use changes. The number of trips is also fixed in the travel demand model as they are determined by the characteristics of households which are held constant. It is likely the large changes we modeled would also affect trip generation rates, with various factors potentially causing increases (e.g., transit improvements and increased density) and decreases (e.g., VMT taxes). The largest potential limitation; however, is that the current travel demand model was built and calibrated with information about the current population and its experience with current and past transportation infrastructure and policies. The large changes we modeled are far from what most people in the region have experienced and such large changes may result in very different behavior than what the model predicts. Finally, this study was conducted using socio-economic, land-use and network data specific to Albuquerque, New Mexico. In addition to strategies having potentially greater or lesser effects in other regions, their relative effectiveness may also vary. For example, increasing transit level of service in a denser urban area that lacks good transit may be more effective than increasing density.

Our analysis focuses on the change in GHG emissions from vehicle traffic attributable to each strategy that we evaluated. Each strategy would provide a range of additional benefits. For example, reductions in VMT would also reduce toxic vehicle emissions and potentially reduce traffic crashes. Increases in active travel such as biking and walking could improve public health. More compact development could also further reduce GHG emissions through small dwelling units and the increased thermal efficiency of multiunit buildings. Most of the strategies we evaluated also reduced travel time and congestion. A full benefit cost analysis of these strategies is beyond the scope of our study which is focused on what is possible rather than what is most cost effective. However, consideration of the full range of benefits and costs of the strategies we have evaluated, those considered in prior studies that have focused on vehicle efficiency and fuel decarbonization, and the mitigation potential in other sectors, should be part of any process that aims to implement an aggressive GHG mitigation strategy.

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